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(56) Documents Cited
GB 2283504 A GB 1360387 A JP 0902152(
JP 070039098 A

(58) Field of Search
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(54) Abstract Title

Air-gap winding impregnated with magnetic material in a binder

(57) An air-gap winding, in which the magnetic flux is caused to pass through a magnetic material (40) rather than through the strands of the winding which are typically made from non-magnetic material such as copper, comprises mixture of discrete particles of the magnetic material (40) and a binder (41) impregnated into the winding under pressure, particularly in gaps (43) between individual wires (50) of the winding and in gaps between individual strands (42) in the wires (50). To avoid unsuitable deformation of the winding, the winding is non-circular in section, so that the mixture (40,41) is forced inwardly and outwardly through cavities formed between a stator (27) and the winding, and between the winding and a cylindrical inner member (32). Litz wire is used as for the individual wires 50.

Fig. 2

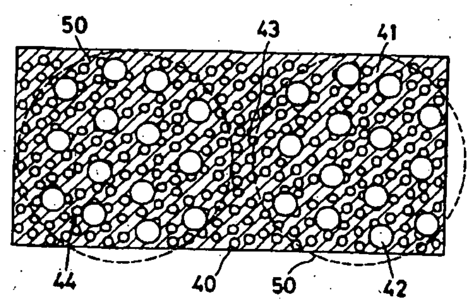
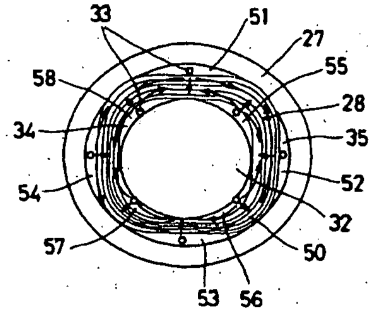


Fig. 3



At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

Fig. 1

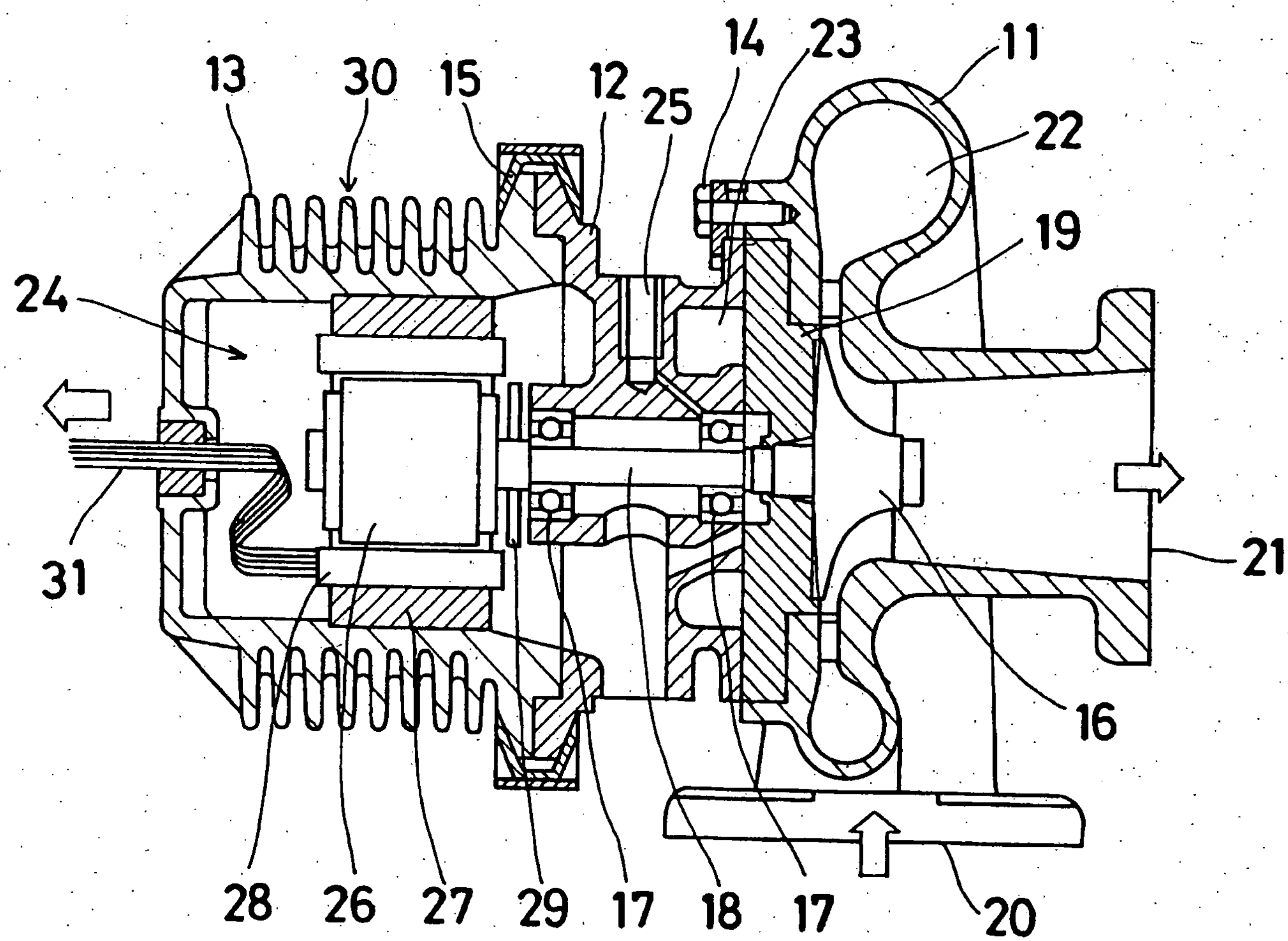


Fig. 2

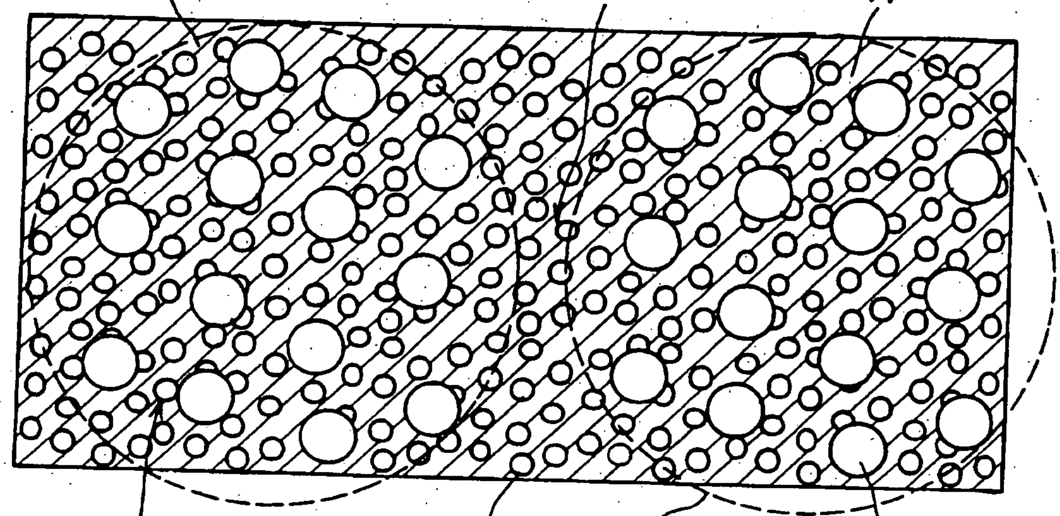


Fig. 3

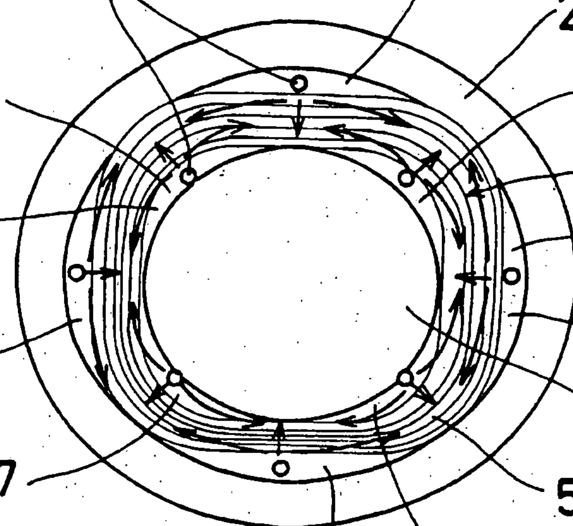
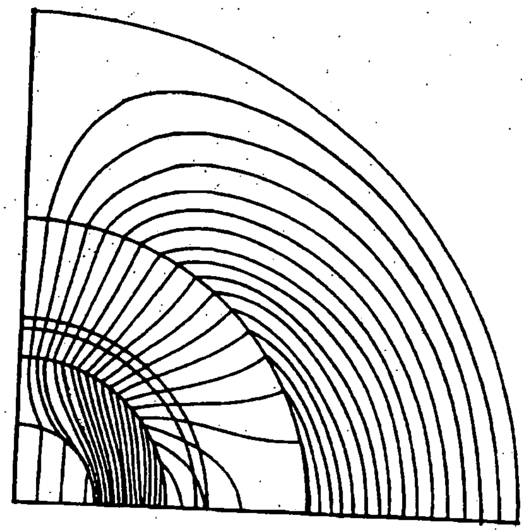
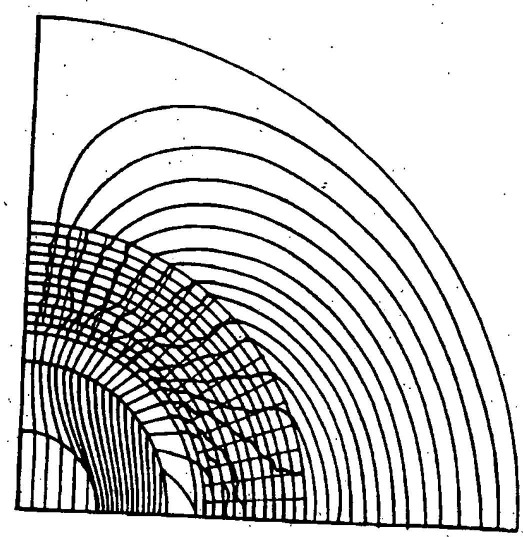


Fig. 4



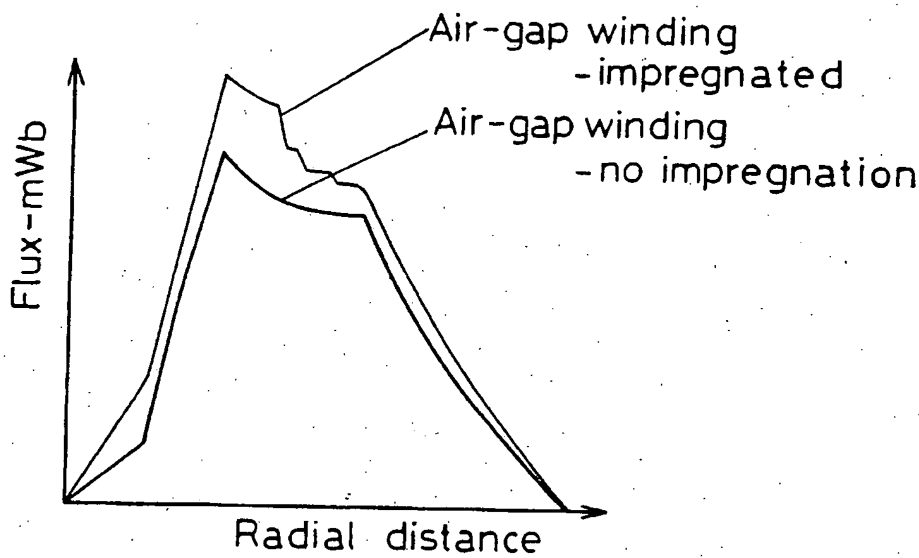
Air-gap winding
-No impregnation

Fig. 5



Air-gap winding
-Impregnated

Fig. 6


Air-gap winding
-impregnated
Air-gap winding
-no impregnation
Flux-mWb
Radial distance

TITLE

Air-gap winding

DESCRIPTION

Field of the Invention

The invention relates to an air-gap winding for a dynamoelectric machine, and in particular for a machine with a rotor, such as a permanent magnet rotor, a solid rotor, an induction rotor or a hysteresis rotor. In such a machine a winding wound in the gap between the rotor and a stator is known as an air-gap winding and may be a helical winding (Faulhaber winding), a Rhombic winding or a Gramme winding.

Description of the prior art

The majority of dynamoelectric machines have windings which are wound in slots in the stators, as shown in Japanese Patent Publication No. 03(1991)-070440A. A stator is made from a material having a relative permeability greater than 1 so as to provide the lowest reluctance path via teeth. The above Japanese Patent Publication shows also winding moulded by a magnetic powder and a binder (e.g. iron + nylon). However, the moulding of the magnetic powder and the binder merely moulds the winding as a whole so as to encourage magnetic flux to pass around the winding. Japanese Patent Publications No. 04(1992)-236142A, No. 06(1994)-197484A and No. 07(1995)-039098A also disclose similar windings moulded as a whole by the magnetic powder and the binder. The moulding around the winding could be considered a logical step to reduce material or mass-production cost. It is simply replacing one material, namely the steel laminations, with another, e.g. the iron and nylon mixture, but both materials have the same function which is to carry flux around the winding.

For some applications it may be desirable to omit the teeth, creating a so-called toothless air-gap winding. Such toothless air-gap windings are used, for example,

- for superconducting machines which contain such a high magnetic field that any teeth would be magnetically saturated,
- for small motors for servo applications where it is desired to eliminate torque ripple caused by the change in reluctance between the slot openings and teeth, and/or
- for high-speed machines where the iron losses in the teeth become a major problem.

The toothless winding is placed directly in the air-gap between the rotor and stator. However, copper which is the usual material of the winding is non-magnetic and so the winding significantly increases the reluctance of the magnetic path. For machines which have normal permanent magnet excitation (e.g. the remnant flux density Br = 1 Tesla), and which require a thicker winding (e.g. 15 mm) to achieve the required power, the increase in reluctance results in a significant reduction in magnetic flux and performance. An additional problem is that the flux passing through the winding produces an additional eddy-current loss in the wires, in the same way as for a conventional machine.

Summary of the Invention

It is an object of the invention to increase the magnetic flux density of an air gap winding for dynamoelectric machines. The invention provides an air-gap winding formed from wires made from a number of strands twisted together, with a mixture of a magnetic material and a binder impregnated in gaps between the wires and in gaps between the strands in the wires. If such an air-gap winding is used in a dynamoelectric machine with permanent magnet excitation, the magnetic flux passes through the magnetic material rather

than through the strands of the winding which are generally made from non-magnetic material, such as copper.

The invention also provides an air-gap winding wherein in section the winding is non-circular in shape, but is built up into a cylindrical body by the mixture of magnetic material and binder. To achieve that, the built-up portions of the mixture of magnetic material and binder are arranged alternately inside and outside of the winding to create cylindrical internal and external shapes for the composite body.

The invention also provides a method for the manufacture of an air-gap winding comprising:

a first step of locating a non-annular winding between cylindrical inner and outer members;

a second step of covering the ends of the winding and the members by covers which include injection gates located adjacent to cavities formed between the non-annular winding and the cylindrical inner and outer members;

a third step of injecting a mixture of a magnetic material and a binder through the injection gates into the cavities and into gaps formed between wires of the winding and between individual strands of those wires; and

a fourth step of removing the covers.

<u>Description of the Drawings</u>

Fig. 1 is an axial section though a turbine-alternator incorporating an air-gap winding according to the invention,

Fig. 2 is an enlarged section in part of the winding in Fig. 1,

Fig. 3 is a cross-section through the air-gap winding during manufacture,

Fig. 4 is a simulation result of the magnetic flux in a conventional air-gap winding,

Fig. 5 is a simulation result of the magnetic flux in an air-gap winding according to the invention, and

Fig. 6 is a graph of the comparative magnetic flux densities of the air-gap windings of Figs. 4 and 5.

Detailed description of the Invention

Fig. 1 shows a turbine-alternator in which a housing comprises three parts, namely a turbine housing 11, a bearing housing 12 and an alternator housing 13. The turbine housing 11 is fixed to the bearing housing 12 and the alternator housing 13 is fixed to the bearing housing 12. A turbine rotor 16 is rotatably supported on ball bearings 17 via a shaft 18 and is located in the turbine housing 11. An air bearing or another bearing (not shown) may replace the ball bearings 17. Between the bearings 17 and the back of the rotor 16, a heat insulator 19 is located. An inlet 20, an outlet 21 and a scroll 22 are integrally formed in the turbine housing 11. A water channel 23 is formed in the bearing housing 12 so as to cool the housings 11,12 and to insulate against heat transfer from the exhaust to the bearings 17 and an alternator 24. An oil passage 25 is also formed in the bearing housing 12 so as to lubricate the bearings 17 and to insulate against the above heat transfer. The alternator 24 comprises a rotor 26 fixed to the end of the shaft 18, a stator 27 and winding 28. One end of an electricity line 31 is connected to the winding 28.

A mixture of a magnetically permeable material (magnetic material) 40 and a binder 41 is impregnated under pressure between the individual strands 42 in the winding 28, as shown in Fig. 2. The binder 41 is typically epoxy, phenolic or polyester resins or a plastic such as nylon or polypropylene, whilst the magnetically permeable material 40 may be iron, nickel, cobalt, or the associated alloys such as silicon-iron, or ferrite. The material 40 is treated to give it an insulating coating and overall the material 40 and the binder 41 mixture 29 is non-conducting to minimise eddy-current loss. Since the magnetic flux passes through the magnetically permeable material 40 rather than through the

strands 42 of the non-magnetic winding 28, the following advantages are observed:

- the magnetic reluctance of the winding 28 is reduced in the radial direction thereof,
- the magnetic flux linking the winding 28 is increased and the voltage and power from a given size of winding 28 are increased,
- eddy current loss is reduced, and
- the thermal conductivity of the winding 28 is increased and the transfer of heat from the winding 28 to the stator 27 is improved.

The particular type of the winding 28 illustrated in Figure 1 is a helical winding. In the helical winding 28 each turn is approximately in the form of a helix as it passes around the stator 27. Each turn is made from a so-called Litz wire 50. Namely, each wire 50 is made from a number of strands (typically between 7 and 28) twisted together to minimise circulating currents in the winding 28. Both gaps 43 between the wires 50 in the winding 28 and gaps 44 between individual strands 42 in the Litz wire 50 are filled with the mixture 29, so that the magnetically permeable material 40 is present in both such gaps 43 and 44. The Litz wire 50 has the features that it comprises small diameter strands and that the strands are intertwined. The former helps to minimise eddy-currents and the latter helps to minimise unbalanced induced voltages and parasitic circulating currents. Typically the helical winding is 2-pole, 3-phase with two layers, although any other combination is possible. The advantages of using a helical winding are an elimination of iron loss in the teeth, a short axial length and a low reactance.

The magnetic flux density of the air gap winding machines is increased according to the invention as shown in Figs. 4 to 6. Fig. 4 shows a simulation result of the magnetic flux using a conventional winding and Fig. 5 shows a simulation

result of the magnetic flux using a winding according to the embodiment of the invention. Fig. 6 shows the increase of the magnetic flux density by comparison of the windings in Figs. 4 and 5.

The embodiment of Figure 1 is of a turbine-alternator, but the air-gap winding of the invention can be obviously applied to other machines, such as a hybrid-charger for an engine. A hybrid charger can work in any of three ways depending on the working condition of the engine:

(1) It can work as a turbocharger when the electric motor/generator (the air-gap machine) is not working.

(2) Both the electric motor and the turbine impeller can drive the compressor impeller to supply compressed air to the engine.

(3) When there is no need or little need for a turbocharger power boost, the turbine impeller drives the motor/generator as a generator to recharge the vehicle's battery, thus reclaiming a large proportion of the energy in the exhaust gas.

Referring to Fig. 3, the stator 27 and the air-gap winding 28 may be manufactured as a single unit according to the following steps:

Step 1, Preparation:

The ring-shaped stator (outer member) 27, the generally square sectional shaped helical winding 28 and a cylindrical inner member 32 are coaxially assembled, and both ends of the stator 27 are closed by end covers (not shown). A number of injection gates 33 are formed through the cover or the covers. Since the winding 28 is of generally square-section, four inner cavities 34 exist between the winding 28 and the cylindrical inner member 32 and four corresponding outer cavities 35 exist between the stator 27 and the winding 28. Alternatively other generally polygonally shaped (ellipse, triangle, square, pentagon) section windings can be used.

Each of the injection gates 33 is located alongside one of the cavities 34,35.

Step 2, Injection moulding:

The mixture 29 of magnetically permeable material 40 and binder 41 is forced into the cavities 34 and 35 through the gates 33, and becomes impregnated in the gaps 43 and 44 in the winding 28 inwardly from the cavities 35 and outwardly from the cavities 34. As shown by arrows in Fig. 3, even pressure is applied to the winding 28 inwardly and outwardly, so that no unsuitable deformation of the winding 28 arises.

Step 3, Completion:

The covers and the cylindrical inner member 32 are then removed so that the stator 27 and the air-gap winding 28 are integrally finished. The winding 28 comprises wires 50, and built-up portions 51 to 58 of the mixture reciprocally located inside and outside of the wires 50.

Claims

1. An air-gap winding for a dynamoelectric machine, wherein the winding is formed from wires made from a number of strands twisted together, with a mixture of a magnetic material and a binder impregnated in gaps between wires and in the gaps between the strands in the wires.

2. An air-gap winding according to claim 1, wherein in section the winding is non-circular in shape but is built up into a cylindrical body by the mixture of magnetic material and binder.

3. An air-gap winding according to claim 2, wherein in section the winding is generally square in shape.

4. An air-gap winding according to claim 1, wherein the winding is a helical winding.

5. A method for the manufacture of an air-gap winding comprising:

a first step of locating a non-annular winding between cylindrical inner and outer members;

a second step of covering the ends of the winding and the members by covers which include injection gates located adjacent to cavities formed between the non-annular winding and the cylindrical inner and outer members;

a third step of injecting a mixture of a magnetic material and a binder through the injection gates into the cavities and into gaps formed between wires of the winding and between individual strands of those wires; and

a fourth step of removing the covers.

The Patent Office

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INVESTOR IN PEOPL

Application No: GB 9906904.9
Claims searched: 1-5

Examiner: John Cockitt
Date of search: 17 August 1999

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.Q): H2A [AKC1, AKD1, AKH1, AKH2]

Int Cl (Ed.6): H02K [1/02, 3/00, 3/02, 3/04, 3/47]

Other: ONLINE: EPODOC, WPI, JAPIO

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
Y	GB2283504A	KOLLMORGEN - air gap winding with magnetic material - eg p17 ln7-14	1 at least
Y	GB1360387A	INTERNATIONAL - see p1 lns32-47	1 at least
Y	JP070039098A	MATSUSHITA - windings embedded in magnetic resin.	1 at least
Y	JP090215282A	TOYOTA - winding strands impregnated	1 at least

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.